# Mid-Frequency Shallow Water Studies and SW06 (LEAR)

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## LONG-TERM GOALS

To develop physics-based, predictive sonar models for:

(a) propagation and detection in littoral conditions

(b) mid- to high-frequency acoustic scattering and reflection from the air-sea interface.

## OBJECTIVES

(1) Analyze, model, and report results from Asian Seas International Acoustics Experiment (ASIAEX) conducted in the East China Sea (May-June 2001).

(2) Prepare for 2006 LEAR (Littoral Environmental Acoustics Research) experiment in 2006 (a follow-on experiment to ASIAEX).

## APPROACH

The approach involves a combination of data analysis (ASIAEX data), theoretical modeling (scattering theories, van Cittert-Zernike theorem) and numerical simulation (RAM PE code).

For LEAR, the approach is directed toward new experimental array development and experimental planning.

## WORK COMPLETED

*ASIAEX East China Sea program coordination*: Fourteen journal articles originating from the Asian Seas International Acoustics Experiment (ASIAEX) East China Sea program were published in the IEEE *J. Oceanic Eng*. Special Issue on Asian Marginal Seas, (October 2004) for which the PI served as Guest Editor.

*New results in 2005 from ASIAEX*: Two papers on the subject of mid-to-high frequency propagation were submitted: "The East China Sea as an Underwater Acoustic Communication Channel: Measurements of the Channel Impulse Response (U)" submitted to the *USN J. Underwater Acoustics*, (July 2005) and *"Measurement and Simulation of the Acoustic Channel Impulse Response for a site in*

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*the East China Sea" submitted to the J. Acoust. Soc. Am. (September 2005).* Key results from these papers are discussed further in the next section.

Additional work completed pertains to LEAR planning, for which the primary effort will be documented in next year's report.

## RESULTS

Key results involve measurements made during the Asian Sea International Acoustics Experiment (ASIAEX) conducted in the East China Sea (depth 105 m) [1], involving CW and FM transmit waveforms in the 8 kHz to 16 kHz frequency range.

Figure 1 summarizes one measurement set, range 416 m, taken on 31 May at 13:54 UTC during which the wind speed was 7 m/s and rms waveheight was ~0.3 m. The right-hand side of Fig. 1(a) shows eigenrays corresponding to the first six arrivals: direct (D), sea surface (S), bottom (B), surface-bottom (S-B), bottom-surface (B-S), and surface-bottom-surface (S-B-S) paths in this order and are computed using a ray-based propagation code based on the sound speed profile [Fig. 1(a), left]. The received intensity level for the CW pulse [Fig. 1(b)] and the amplitude of the matched filter output for FM pulse [Fig. 1(c)] are referenced to those of the peak value for the direct path. (The FM case is plotted in amplitude space for ready comparison with other results of this kind.) At this ~0.5 km range, there are essentially six paths that deliver the waveform, corresponding to the eigenrays in Fig. 1 (a), all of which interacted with the bottom one time or less (a range of approximately 1.7 km is required for bottom loss to be significantly reduced by pre-critical angle effects). The standard deviations for both data sets is ~5.6 dB, and is consistent with the standard deviation for a time-resolution-bandwidth product close to unity [2]. An exception consists of the D and B paths shown in the CW case, that are not subject in fluctuations of the kind imposed by the sea surface, and for which the standard deviation is 4.1 dB and 2.5 dB, respectively. The corresponding portions for the FM case are not distinguishable owing to the impulse-like shape of the matched filter output.

These data are modeled using an approach diagrammed in Figure 2. This involves generation of a model for the intensity channel impulse response, $I^c(t)$; the expression for $I^c(t)$ is equivalent to a time-averaged response, and embodies the boundary scattering and reflection physics corresponding to the center frequency at which computations are made. To compute $I^c(t)$, the separate impulse response functions from each arrival, such as the single surface bounce (S), and surface-to-bottom bounce (B), as shown in Fig. 2 , are modeled using bistatic scattering concepts, and are incoherently summed for the total response function.

To compare with observations $I^c(t)$ is convolved with representations of the 8 kHz and 16 kHz continuous wave (CW) pulses, and a 8-16 kHz frequency modulated (FM) pulse used during ASIAEX. Figure 2 (b) shows a comparison with data for which the transmit pulse was a 8 kHz CW pulse of length 2 ms. (It is found that six primary arrivals deliver the waveform for ranges less than about 1 km, and modeling of $I^c(t)$ is limited to these paths.)

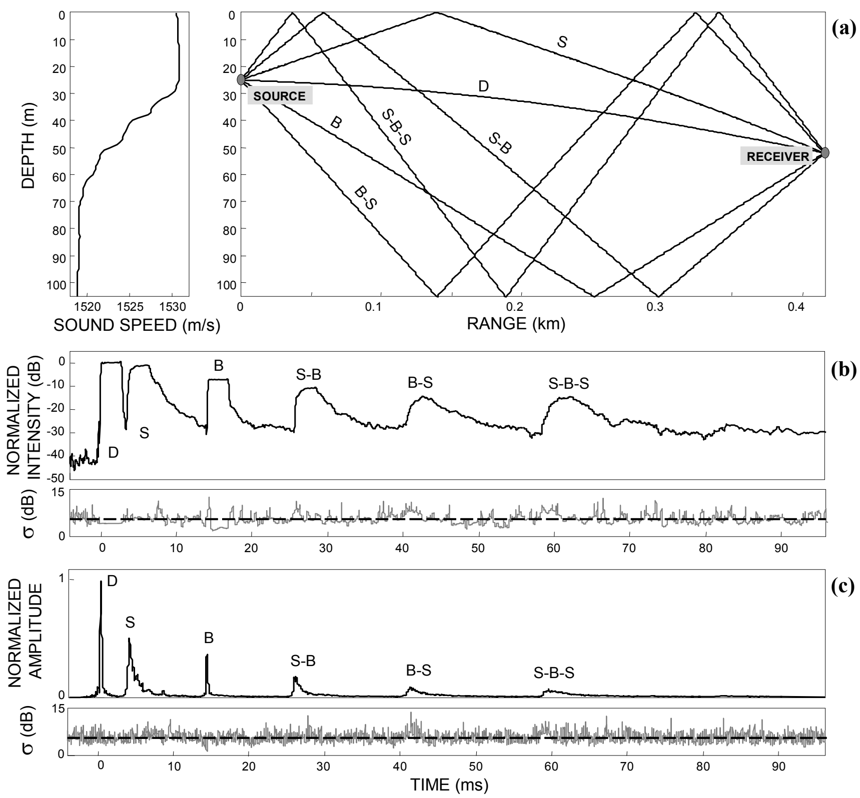


***Figure 1. (a) First six eigenrays (right-hand side) for source depth 25 m, receiver depth 52 m and range 416 m based on the average sound speed profile (left-hand side) corresponding to time of acoustic measurement. (b) The measured averaged intensity and the standard deviation expressed in decibels for the 16 kHz CW signal. (c) The measured averaged amplitude of the matched filter envelope output for the LFM signal and its standard deviation expressed in decibels (averaging performed in intensity domain and square root taken). The dashed line in the standard deviation plots indicates 5.6 dB. Measurements were taken on 31 May at 13:54 UTC during which the wind speed and rms waveheight were 7 m/s and ~0.3 m, respectively.***

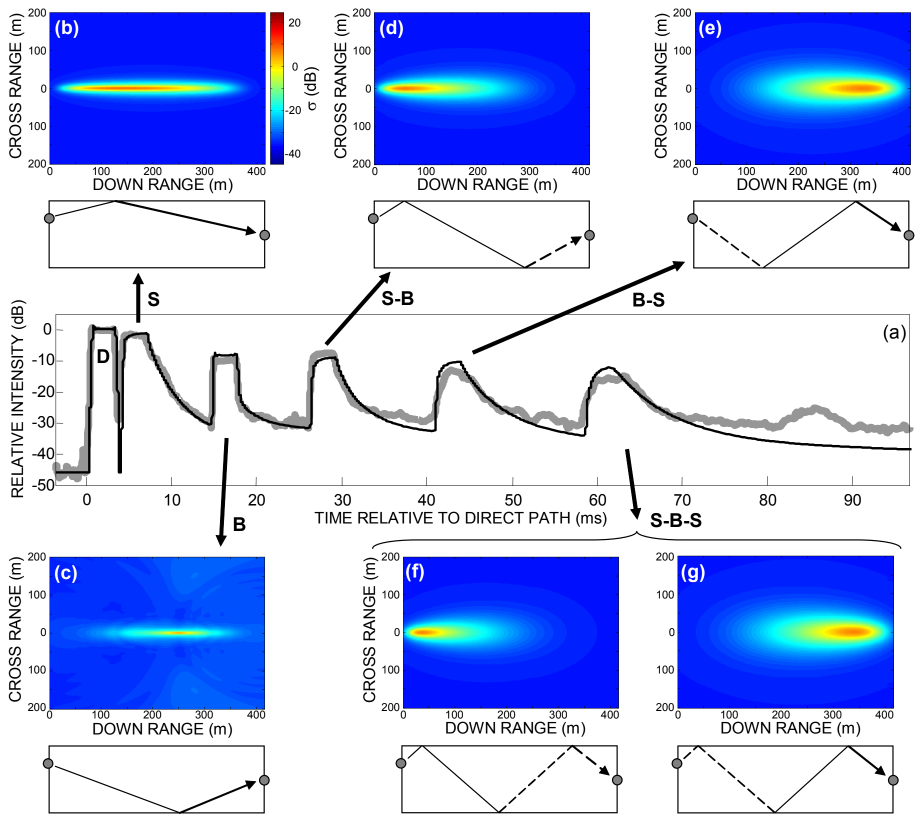


***Figure 2. (a) Comparison between the predicted intensity level (black line) and measured averaged intensity (thick gray line) for the 8 kHz CW signal, from that same experimental set discussed in Fig. 1. The intensity level is referenced to that of the mean peak value for the direct path. Figures (b), (d), and (e) are maps of the sea surface bistatic scattering cross section for the S, S-B, and B-S paths, respectively, and (c) is a map of the bistatic cross section (incoherent + coherent) for the B path. Figures (f) and (g) show maps of the sea surface bistatic scattering cross section for computing $I^{sbs'}(t)$ and $I^{s'bs}(t)$, respectively, which are subsequently convolved to predict the impulse response for the S-B-S path. The ray diagram below each bistatic cross section map shows the corresponding specular ray path, for which a dashed lines indicates a specular reflection.***

For the FM case, the computation frequency is 12 kHz or the center frequency of the FM pulse and $I^{c}(t)$ is convolved with the squared autocorrelation function of the FM pulse. Like the CW results in shown in Figure 2(a), Figure 3 shows that FM measurements compare well with their model equivalents including fair agreement in the relative amplitudes between the direct and boundary interaction paths, and in the relative amplitudes between the two experimental runs.

In summary, we find that the basic structure of the impulse response $I^{c}(t)$ is set by bottom loss and acquisition geometry with some changes in intra-path time spreading that depend on sea surface conditions. Our approach represents a new capability in modeling the impulse response for shallow-water, multi-path propagation.

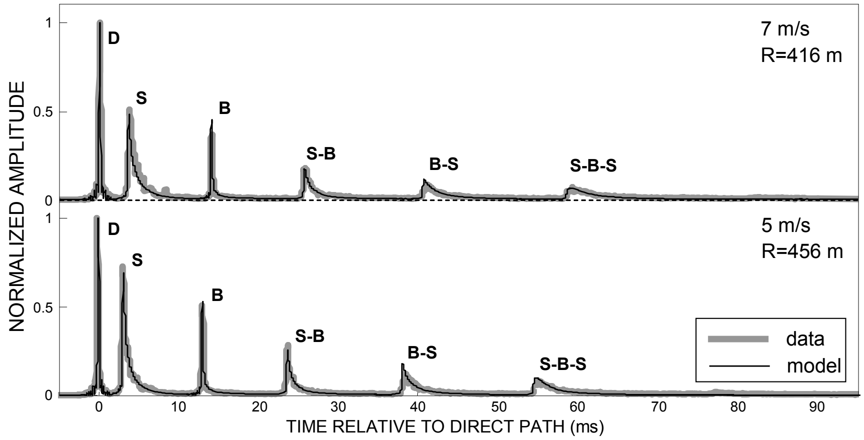


***Figure 3. Averaged envelope for the matched filtered output over 20 pings for measurement made 31 May at 13:54 UTC (upper plot) during which wind speed was 7 m/s, and measurement made 1 Jun at 01:05 UTC (lower plot) during which wind speed was 5 m/s, compared with equivalent model. The source and receiver depths are 25 m and 52 m, respectively. The averaged envelope is the square root of a linear intensity average over 20 transmissions, and the amplitude is referenced to that of the peak value for the direct path.***

## IMPACT/APPLICATIONS

ASIAEX East China Sea, along with its South China Sea counterpart, provide key data base support for
areas emphasized in ONR Persistent Littoral Undersea Surveillance (PLUS) program.

The techniques developed here represent a new capability in modeling the impulse response for shallow-water, multi-path propagation, with direct application to acoustic communication.

## TRANSITIONS

The ASIAEX East China Sea (ECS) results will in the future provide important benchmark data on the mean, and variability, of several sonar metrics applicable to strategic WESTPAC regions for use in TDAs. ASIAEX data [1,3] relating to attenuation from near-surface bubbles, is also being utilized for improvement of OAML sonar models.

## RELATED PROJECTS

This research is integrated together with several projects within the ASIAEX field program (James Miller (URI), D. Tang (APL-UW), Jixun Zhou (Georgia Institute of Tech), and Zhaohui Peng (Institute of Acoustics, Beijing), with focus on propagation, and surface scattering and reflection, bottom reflection, and volume scattering effects in the East China Sea. The OMAL sonar modeling work (Roger Gauss, *et al*., NRL) is utilizing ASIAEX data.

The PI is working with D. Tang (APL-UW) to coordinate environmental and acoustic measurements for LEAR.

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